Renewable and Sustainable Energy Reviews 38 (2014) 561–571

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Internal combustion engines: Progress and prospects

Avinash Alagumalai

Internal Combustion Engineering Division, Department of Mechanical Engineering, Sri Venkateswara College of Engineering, Sriperumbudur 602105, Tamil Nadu, India

ARTICLE INFO

Article history:
Received 17 March 2014
Received in revised form
5 May 2014
Accepted 18 June 2014

Keywords:
Engine
Alternative fuel technology
Performance
Emission

ABSTRACT

Indeed, the engine industries have seen a tremendous growth in the research and development of new-age technologies over the past ten years or so. Even though a huge database is now available on present-day engine technologies, a skillful presentation of those data is a demanding task. At this count, an endeavor has been made here to brief the pros and cons of present-day engine technologies in an elusive manner. In a nut–shell, this article provides an extensive review of the primary principles that preside over the internal combustion engines design and operation, as well as a simplifying framework of new-age engine technologies has been organized and summarized in an elegant way to contribute to this pragmatic field.

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E-mail address: avinashandromeda@gmail.com

http://dx.doi.org/10.1016/j.rser.2014.06.014
1364-0321/

1. Introduction

Perhaps the most graceful invention by humankind that ever had a greater impact on society, the economy, and the environment is the reciprocating internal combustion engines, in general called as IC engines [1,2]. Although several researchers made noteworthy contributions in the development of IC engines, the historical breakthrough by Nicolaus Otto (1876) and his counterpart Rudolf Diesel (1892) in the development of Spark Ignition (SI) engine and Compression Ignition (CI) engine is globally praised [3,4]. For decades, their magnificent inventions proved to play a vital role in the automobile system, used almost exclusively today.

Unfortunately, at present there is a pressing need to develop advanced combustion engines that maximize the engine efficiency and totally mitigate the exhaust emissions [5,6]. In this regard, the hybrid electric vehicles would be the major part of future transportation systems, because of their eco-friendliness and flexibility in operation [7]. Conversely, there are issues like power storage options allied with hybrid electric vehicles yet to be resolved [8]. Thus, undoubtedly hybrid vehicles would be the new age eco-friendly vehicles, which would find a potential global market in near future.

However, focusing on the present day scenario, several studies have been conducted on improving the performance of conventional IC engines by using alternate fuels, without much modification in the engine system [9–12]. Since more than enough of the research studies had been carried out in analyzing the performance and emissions of conventional IC engines by alternate fuels, an attempt has been made in this article to devise the principle design and operating variables, such as compression ratio, ignition period, injection parameters, etc., that influence the engine operation under diverse circumstances. In conjunction, an exertion has been made to discuss briefly the pros and cons associated with non-conventional IC engine's operation.

2. Variables influencing engine performance

While designing any potential heat engine, a formidable challenge lies in designing it to produce a twin advantage of maximum mechanical power and minimum engine-out exhaust, by supplying less energy input to the engine. Although 100% occurrence of the above incident is cumbersome, however, to some extent, the engine's performance could be influenced by varying the design and operating variables. Amongst several variables, the emphasis here is on the combustion chamber geometry, compression ratio, exhaust gas recirculation (EGR), ignition delay, injection parameters, and intake system heating.

2.1. Combustion chamber geometry

2.1.1. Open combustion chamber

In general, a typical IC engine's performance, emission, and combustion characteristics strongly rely on the combustion chamber configuration. To assist the above fact, several noteworthy experimental investigations on the effects of varying combustion chamber geometry were demonstrated by numerous researchers. In that count, Jaichandar et al. [13] studied the effects of varying the open combustion chamber geometry in a single cylinder diesel engine fueled with Pongamia methyl ester. The experimental outcomes revealed improved characteristics for the toroidal combustion chamber when compared to the shallow depth combustion chamber and hemispherical combustion chamber. This trend was principally due to the improved air motion by employing toroidal combustion chamber, which might have enhanced the mixture preparation and combustion mechanism. In the sequence with the above work, a significant contribution was made by Mamilla et al. [14] in evaluating the effects on engine performance by varying the open combustion chamber geometry. The study was carried out in a single cylinder, direct-injection diesel engine fueled with Jatropha bio-diesel. The experimental outcomes proved superior performance characteristics for the toroidal combustion chamber when compared to the other open type combustion chambers.

Besides the experimental investigations on the effects of combustion chamber configurations, various optimization techniques to evaluate the effects of combustion chamber geometry on engine performance were carried out by several researchers. One such contribution was made by Park [15]. Park evaluated the effects of optimization of combustion chamber geometry and engine operating conditions for CI engines fueled with di-methyl ether (DME). In the study, the DME was chosen as an alternative fuel to diesel since DME roughly contains about 35 wt% of oxygen, which would improve the combustion characteristics. In addition, the study stressed the need of optimization of combustion chamber to achieve considerable improvement in the engine operating characteristics.

2.1.2. Divided combustion chamber

In the past twenty five years or so, abundant research works had been carried out in a direct injection combustion chamber (open combustion chamber) than indirect-injection combustion chamber (divided combustion chamber). This is due to the fact that the use of the divided combustion chamber is often accompanied by high fuel penalties. However, with divided combustion chamber design, vigorous charge motions and faster combustion rates can be achieved [16]. In this regard, Rakopoulos et al. [17] dealt with the determination of combustion mechanisms in the divided combustion chamber. The analysis results provided a basis for construction of the divided combustion chamber, and exhibited the most appealing results with heat release rate mechanism.

2.2. Compression ratio

Like the combustion chamber configuration, the compression ratio (CR) is also an equally important design parameter that has a momentous effect on performance and emission characteristics, because CR is a chief concern for flexible fuel technology development [18]. To substantiate the above actuality, several research works had been carried out by the analysts throughout the world. Below are some of the remarkable contributions made by the researches on the effects of varying CR on the engine performance.

Raheman and Ghadge [19] studied the impact of varying CR of a Ricardo diesel engine fueled with Mahua bio-diesel. It was apparent from the study that the performance characteristics of diesel engine fueled with B20 (20% bio-diesel and 80% diesel) Mauha bio-diesel by varying compression ratio from 18:1 to 20:1 disclosed about 29.5% increase in brake thermal efficiency (BTE). Similar to prior work, Sayin and Gumus [20] investigated the influence of CR on a single cylinder, direct-injection diesel engine fueled with bio-diesel blended diesel fuel. The experimental results showed substantial improvements in BTE, fuel economy, CO, HC, and smoke opacity along with sharp increase in NO*x* emission when the CR was raised from the standard settings.

In recent days, gaseous fuels are attractive owing to their ability to form near homogenous mixture and due to their wider flammability limits. An experimental work by Porpatham et al. [21] on the effects of CR on the performance mechanism of a modified diesel engine operated with bio-gas revealed an increase in BTE, HC and NO emissions to increase in CR. This significant increase was noted to be the highest at the CR of 15:1. The chief reason for